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# Failure analysis in railway wheels

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**Abstract**

This work describes an investigation on underground-train wheel failure. In the railway operation, the contact temperature between the wheel and the rail does not usually achieves values over 300°C; still, in some situations, such as slide or braking system clamping, the thermal energy is high enough to austenitise the material near the surface. Quick cooling is a consequence of the great volume of the wheel. The thermal affected zone is a core for micro cracks, which grow inside the wheel. The present paper studies a real failure case in the Brazilian underground system, where cracks on the contact surface were evidenced. The mechanical properties were evaluated (mechanical strength, ductility, toughness fracture) and a metallurgical analysis (by light microscopy) was performed in order to understand the real cause for the crack nucleation. The studied wheel was manufactured according to the American standard AAR M-107 (Association of American Railway) specification and the mechanical tests (location of the sample and procedure test) were performed in accordance with BS EN 12626 standard (European Standard). The mechanical results are in accordance to MWL Brasil data base (manufacturing historic) to the same material (AAR Class B – 0,5% C). The optical microscopy evidenced the location of the crack origin, and confirmed the overheating region.


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*Keywords:* Fracture, Failures Analysis, Railway Wheels, Thermal Affected Zone.

## 1. Introduction

The idea of using tracked roads is as old as, at least 2000 years. Primitive cars pulled by animals were found in quarries in ancient Greece, Malta and Roman Empire, used for stone transportation Setti, J. B (2000). Time after

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time this concept of transportation system has evolved. The wood rail was replaced by iron rail, the wood wheels received iron protection in the contact surface and, after some years, it was manufactured on iron cast and, nowadays, through forged processing.

The main reasons that justify for these evolutions are: increase of efficiency (more load and speed) and safety.

Nowadays the railway system is a reference on the developed countries, thus the constant studies and research focuses on guarantying further safety Zucarelli, T. A. (2014).

The contact fatigue between wheel and rail is the principal cause of the replacement of these components. The constant inspection is primordial to safety performance.

In the railway operation, the contact temperature between the wheel and the rail does not usually achieves values over 300°C; still, in some situations, such as slide or braking system clamping, the thermal energy is high enough to austenitise the material near the surface. Ahlström, J. et al. (1999). The thermal affected zone is a core for micro cracks, which grow inside the wheel.

Railroad wheel fracture is usually caused from the tip of thermal cracks, and stresses which trigger the fracture are usually produced by abnormal brake heating Sakamoto, et al. (2000).

The present paper studies a real case in the Brazilian underground system, having the intention to demonstrate the importance of good practice during inspections.

## 2. Description of materials

The present paper studies a real failure case in the Brazilian underground system, where cracks on the contact surface were evidenced, as illustrated on Figure 1. The wheel was manufactured according to the AAR M-107 specification (Association of American Railroad) AAR M 107, (2011), with a class material B (0,5% C) by forged processing. The crack was found after 2 years of wheel operation (first life), around 181.000 km. The pressure of wheelset assembly according to the process is 87ton (min: 77ton / max: 110ton).


Figure 1. Defect on contact surface.

## 3. Experimental process

To study the cracks found on the wheel surface, the first step is cutting the wheel without thermal energy input, to avoid metallurgical changes. The falling weight method (1ton - 3m) was applied, and the wheel broke as shown in Figure 2. The original crack was localized in segment 1-2, and this piece is shown in figure 3. The transversal view shows the depth of the crack and it is possible see the thermal affected zone (TZA) in the surface contact. The crack depth is around 12 mm and nucleated in the contact surface, on the same region as the thermal mark.

To analyse the mechanical properties to ensure the quality of material and the manufacture process, mechanical tests (tensile test, impact test, toughness fracture test) and metallurgical analyzes were performed. The location of samples and the method test was performed according to BS EN 12262EN 13262, (2004), and the results were compared with MWL Brasil data base (manufacturing historic).

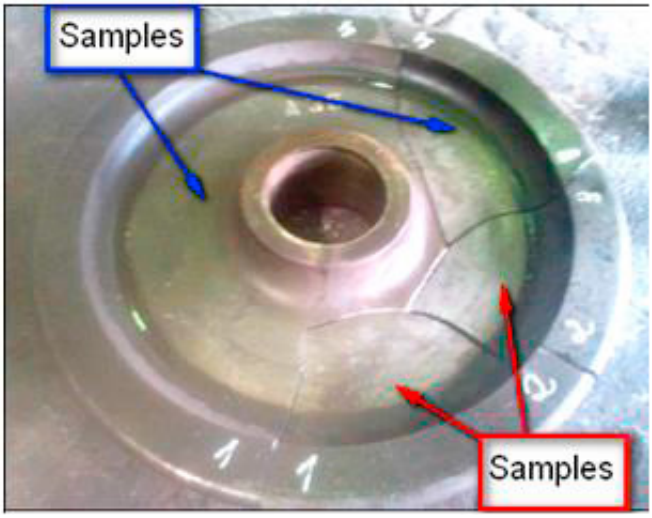


Figure 2. Wheel broken.

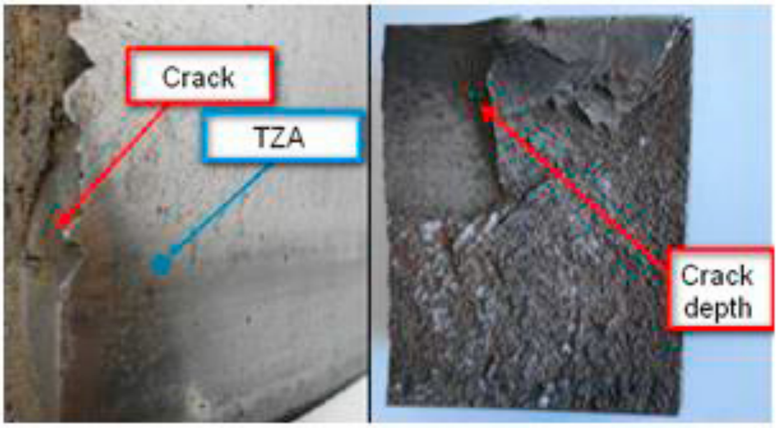


Figure 3. Detail of the surface crack.

## 4. Mechanical and metallurgical tests

To demonstrate and compare the characteristics of the wheel material with the MWL Brasil database, the following tests were performed: tensile test, impact test and toughness fracture test, all tests according to EN 13262EN 13262, (2004). The Figure 4 shows the location of the samples.

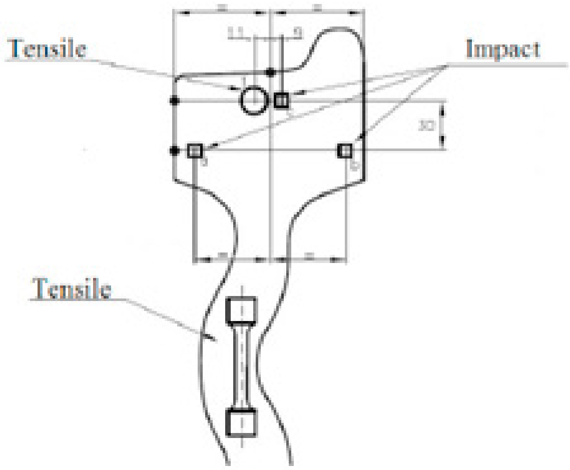


Figure 4. Location of samples (unit: mm).

### *4.1. Tensile tests*

The tensile results are in accordance with MWL data base. They can be seen on Tables 1 and 2.

Table 1. Tensile teste results rim

| Properties | Wheel | Data base |
|---|---|---|
| Yield strength | 645 MPa | 680 MPa |
| Tensile strength | 1049 MPa | 1057 MPa |
| Elongation | 14% | 14% |
| Reduction area | 29,90% | 31% |

Table 2. Tensile teste results web

| Properties | Wheel | Data base |
|---|---|---|
| Yield strength | 396 MPa | 396MPa |
| Tensile strength | 830 MPa | 829MPa |
| Elongation | 15,40% | 15% |
| Reduction area | 24,50% | 27% |

### *4.2. Impact test*

Table 3 shows the impact test results being in accordance with MWL data base.

Table 3. Impact tests results

| Position | Wheel | Data base |
|---|---|---|
| A | 16 J | 14.5 J |
| B | 16 J | 13.7 J |
| C | 17 J | 15 J |
| Average | 16.3 J | 14.4 J |

### *4.3. Toughness fracture test*

The toughness fracture test results are in accordance with the MWL data base (Table 4). The sample was taken at a depth of 17 mm from the surface (tread).

Table 4. Toughness fracture test results

| Position | Wheel | Data base |
|---|---|---|
| A | 66 $MPa.m^{1/2}$ | >50 $MPa.m^{1/2}$ |

### *4.4. Metallurgical analyses*

The produced metallurgic analyses aims at evidencing the overheating region on the transversal section of the tread. The chemical attack was made using Nital etching. It is possible see, in Figure 5, the colour change (dark silver and bright silver). The microstructure in the region is changing from austenite to martensite.

Using optical microscopy, (Figure 6) the microstructure is analyzed and evidence is found that microstructure has changed on the thermal affected zone. In this region, it is possible to visualize martesite and a descarbonized area. The microstructure in the internal region of the wheel is according to the chemical composition (0,5% C) with presence of perlite and ferrite. The crack arises from the ZTA (surface) and grows into the inside wheel.

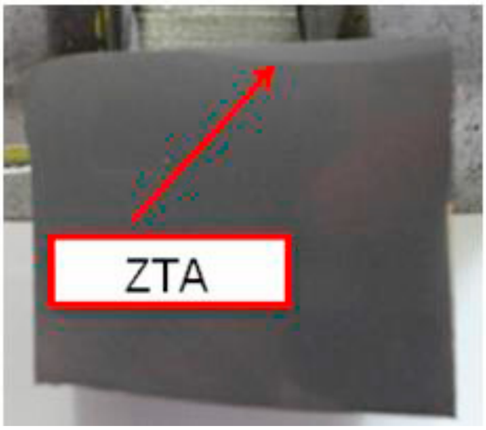


Figure 5. Overheated thin layer.

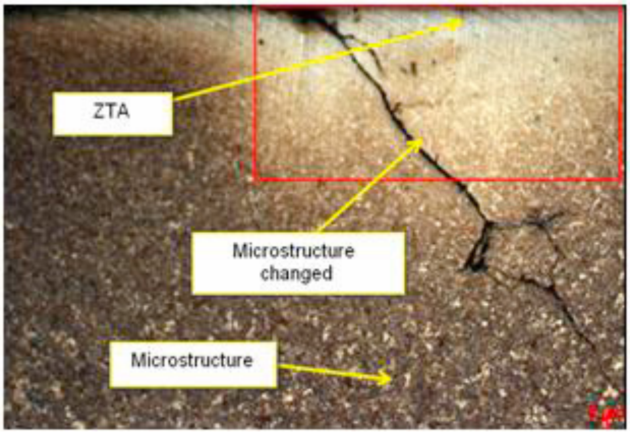


Figure 6. Thermal affected zone microstructure.

## 5. Final remarks

The present work concluded that cracks nucleated from the tread (contact surface between wheel and rail) in the thermal affected zone (ZTA). It was possible to evidence a microstructure change (perlite/ferrite to austenite/martensite), possibly caused by a brake system condition (shoe locking). The crack grew by fatigue process due the cyclic service of the wheel, leading the wheel to fail.

This paper shows that wheel safety is not only relative to mechanical properties nor manufacture process, but as well that serious defects can arise from external factors and operation methods.

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